CHANGING WHAT'S POSSIBLE

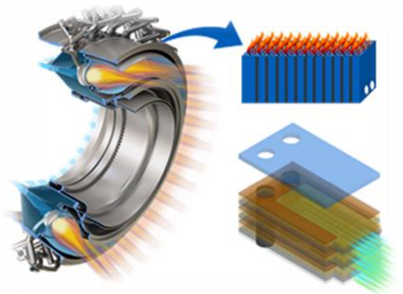
FueL CelL Embedded ENgine (FLyCLEEN)

John Hong, General Electric Research

FLyCLEEN enabling future of clean and sustainable flight

by innovatively integrating high power density Metal-Supported Solid Oxide Fuel Cell (MS-SOFC) with gas turbine genset.

Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REEACH)



REEACH / ASCEND / CABLES
Annual Program Review Meeting
June 28-30, 2022

West Virginia University

PCI
Precision Combustion, Inc.

FLyCLEEN Team

Team member	Location	Role in project
GE Research	Niskayuna, NY	System Design, MS-SOFC Design, Fab & Testing, T2M
Precision Combustion Inc.	North Haven, CT	CPOX Synfuel Reformer Design and Development
West Virginia University	Morgantown, WV	SOFC Anode Protection Coating Development

Dr. John Hong
Lead Combustion Engineer

Gas turbine combustion, Combustion dynamics

Dr. Anil Duggal
Chief Scientist – Energy Materials

Energy Storage, battery, fuel cells, electrical & optical materials and systems

Dr. Hani A.E. Hawa
Research Engineer

H_2 Production, Gas Separation Membranes, Additive Manufacturing

Mr. Richard Hart
Senior Material Scientist

SOFCs, Battery & Energy storages

Dr. Edward Sabolsky
Professor of Mechanical and Aerospace Engineering

Ceramics, Electronic Materials, SOFC/SOECs, Nanomaterials, Ceramic Processing

Subir Roychoudhury, D.E.
VP, Research & Engineering

Fuel Reforming, SOFCs, Catalytic Combustion

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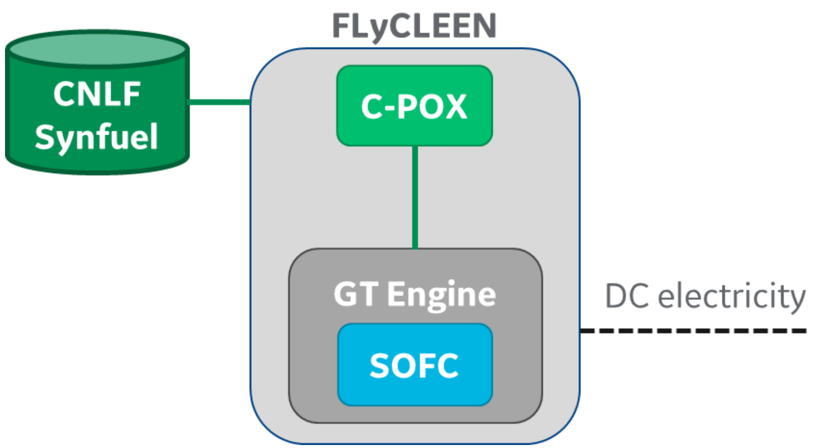
Project Overview & Innovation

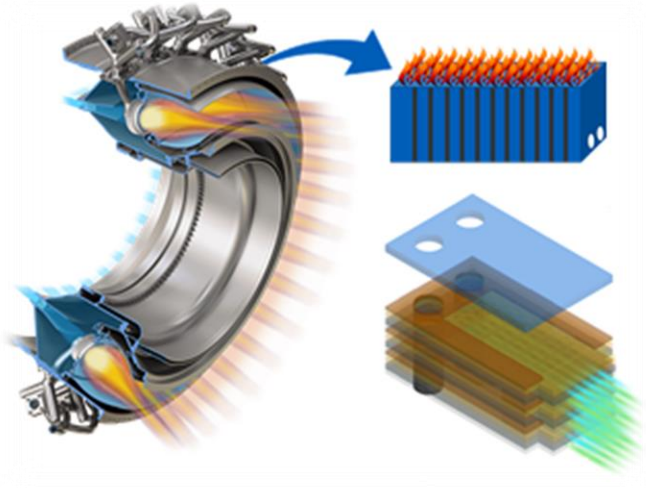
MS-SOFC embedded directly into combustion chamber of gas turbine engine generator

- Leverages gas turbine Balance-of-Plant (BOP)
- Robust MS-SOFC for high pressure, 10x power density
- Synfuel integrated with high-efficiency C-POX
- Thermodynamic synergies with waste heat recovery



Phase 1 Goal is to demonstrate FLyCLEEN concept operability & to develop high specific power, robust SOFC

Performance Metrics	ARPA-e Goal	FLyCLEEN
ESPG system specific energy [kWh/kg]	> 3	~3.7
Powertrain system specific power [kW/kg]	> 0.75	~1.3
Cost of fuel at 100MWh scale [$/kWh]	< 0.15	~0.14
Initial capital cost of ESPG system [$/kW]	< 1000	~940

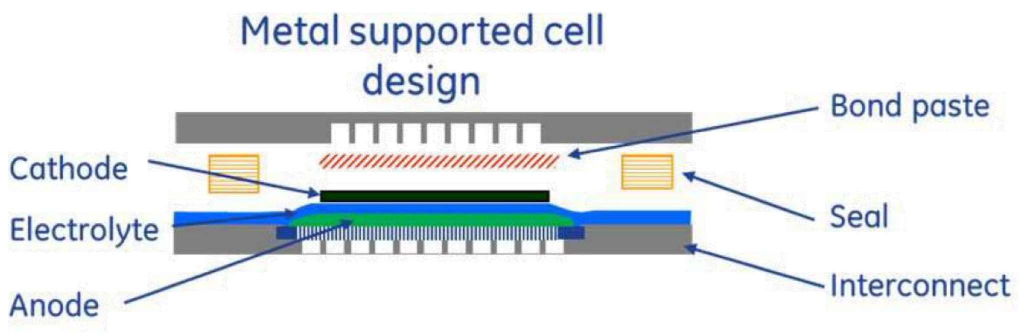


Task Outline & Technical Objectives

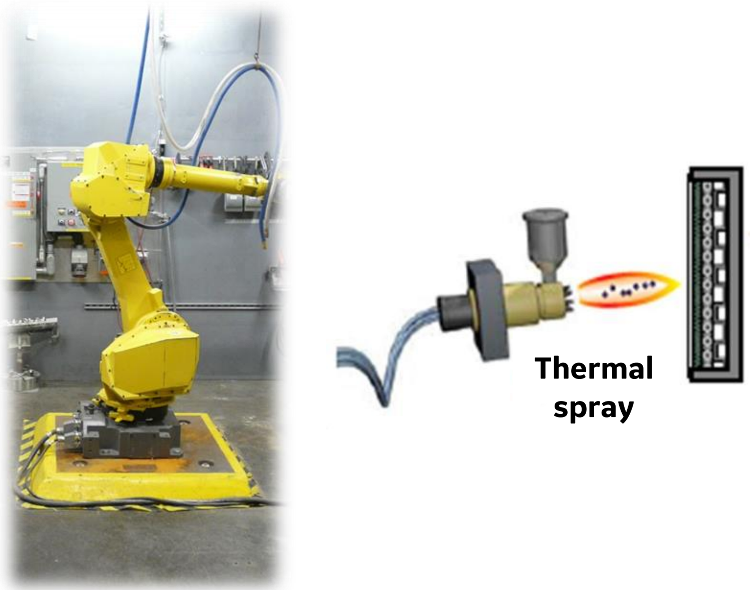
- **Phase 1 Focus:**
  - Develop robust MS-SOFC for high specific power
  - Demonstrate SOFC-Combustion system operation at high pressure
- **Potential Phase 2:** 5kW CPOX-SOFC-Combustion Chamber Prototype fabrication and demo

Phase 1 Tasks	Outcomes
System performance modeling	Ensure FLyCLEEN system meets performance target (power, weight, cost, etc.)
Develop MS-SOFC with low ASR & optimized geometry	MS-SOFC specific power > 1kW/kg
Coupled mechanical-thermal modeling of SOFC	Enable efficient design process of robust MS-SOFC
Integrated sub-system testing at high pressure	System operability demo & robustness of MS-SOFC
C-POX reformer development and design *(by PCI)*	Enable using CNLF for system at high efficiency with desired fuel composition for SOFC
Develop nano anode coating material *(by WVU)*	Improve durability of SOFC electrode

MS-SOFC Development



D. Hickey *et al* 2017 *ECS Trans.*



Metal-Supported (MS) SOFC Stack

- Thin active ceramic coatings on metal substrates
- Most robust for engine environment

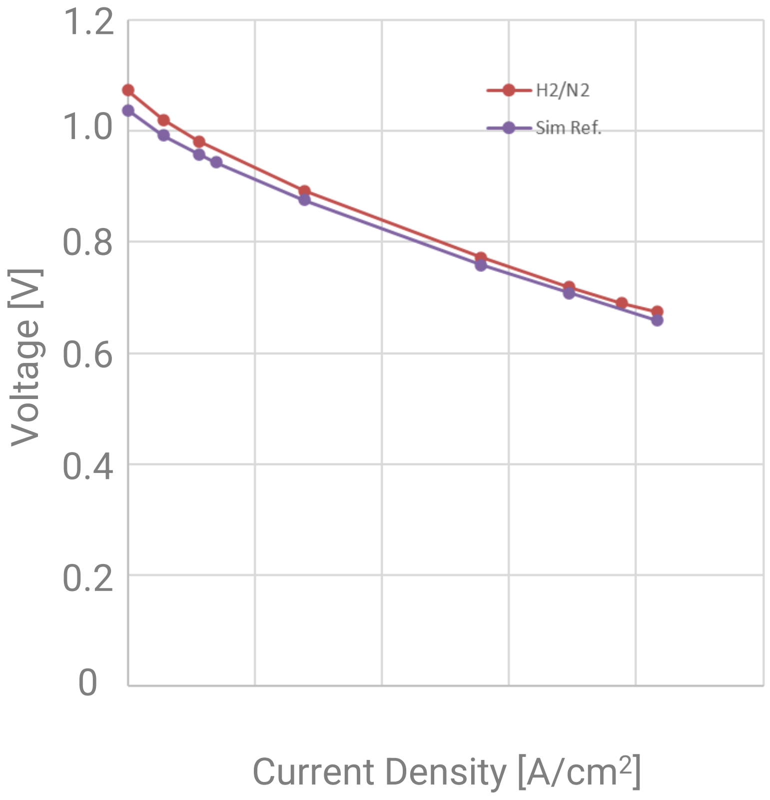
Thermal Spray Method for SOFC fabrication

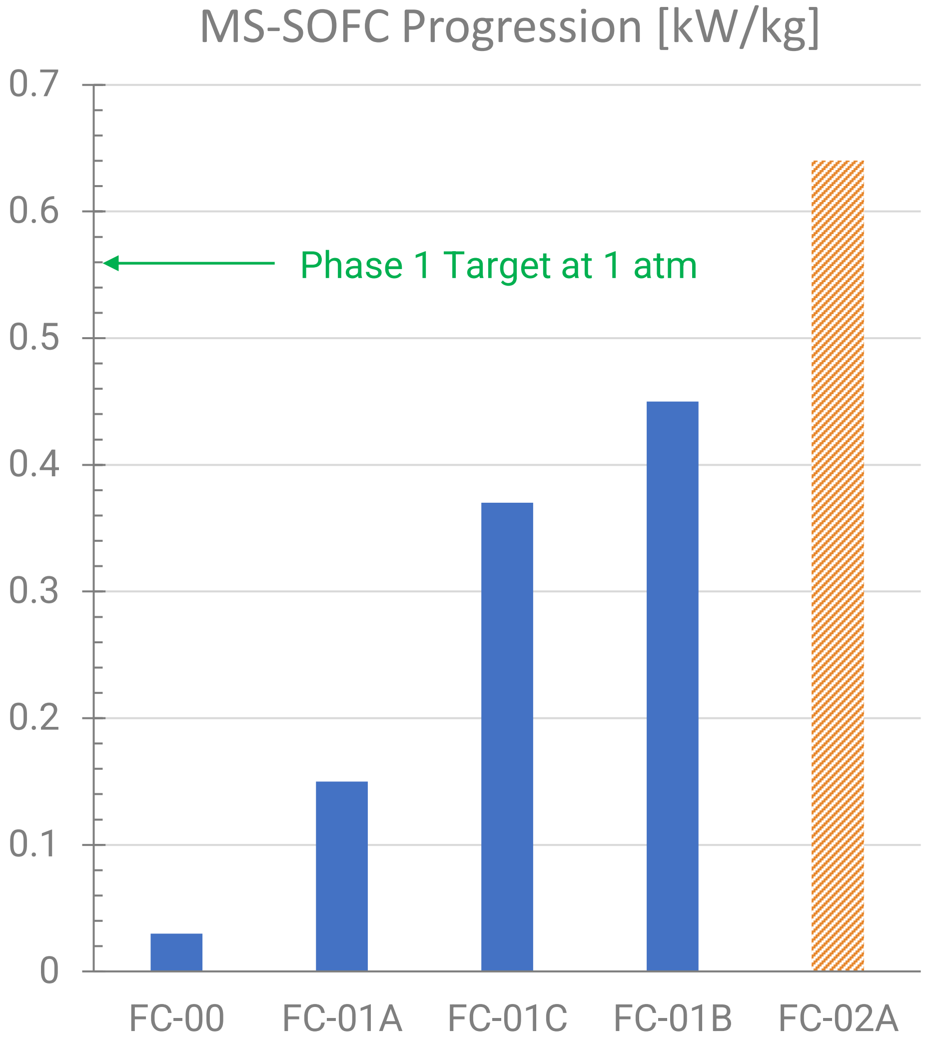
- Low-cost & high-rate deposition
- Allows redesign of structures
- Improved anode electrical contact
- Integrated anode seal

SOFC Performance

Metal-Supported (MS) SOFC 3-Cell Stack

- 80% of Phase 1 power density target achieved
- Specific power 15x improvement during Year 1



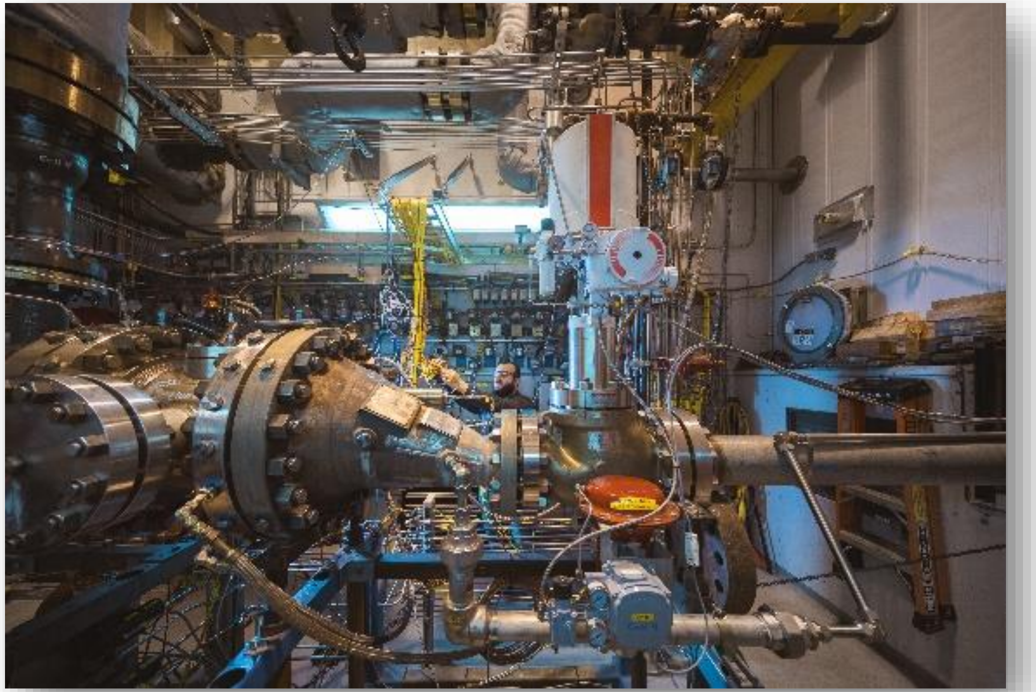


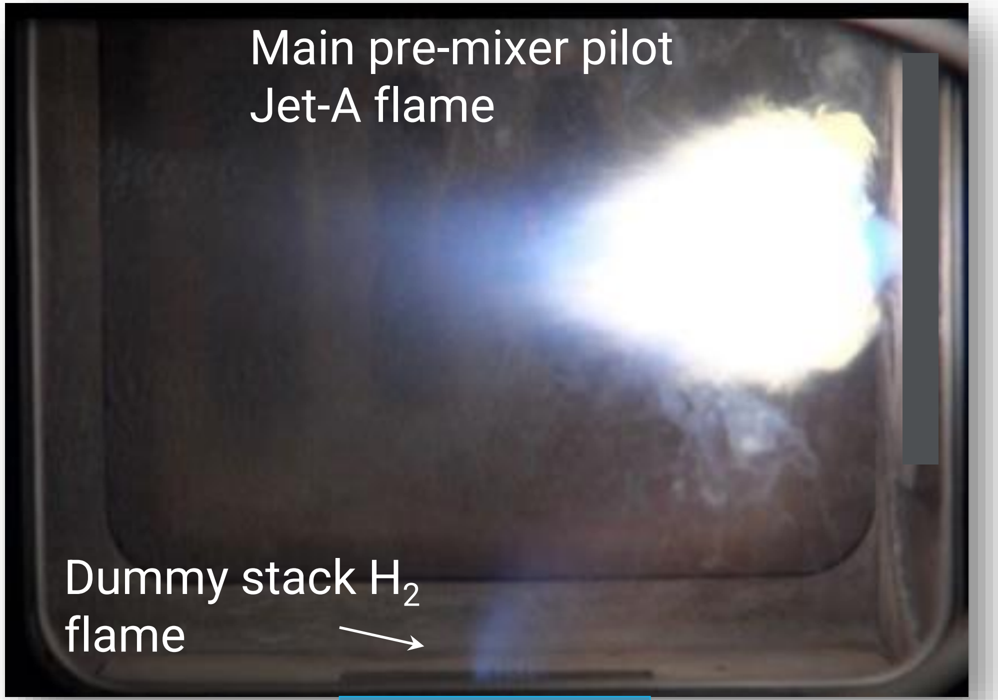
High-Pressure Testing

3-Cell Dummy SOFC Stack Integrated with Combustor

- Tested in a single nozzle rig at ~25-atm in Year 1
- Plan to test 10-cell SOFC stack integrated with combustor in Year 2

✓ Operability at high-pressure
✓ Mechanical integrity





Main pre-mixer pilot Jet-A flame

Dummy stack H_2 flame

Dummy SOFC Stack

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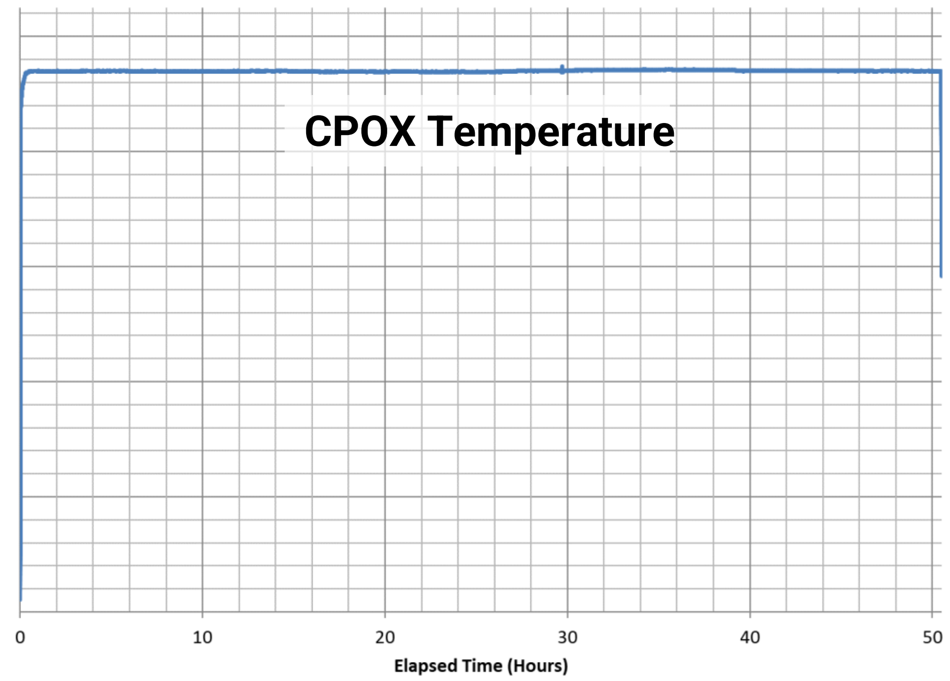
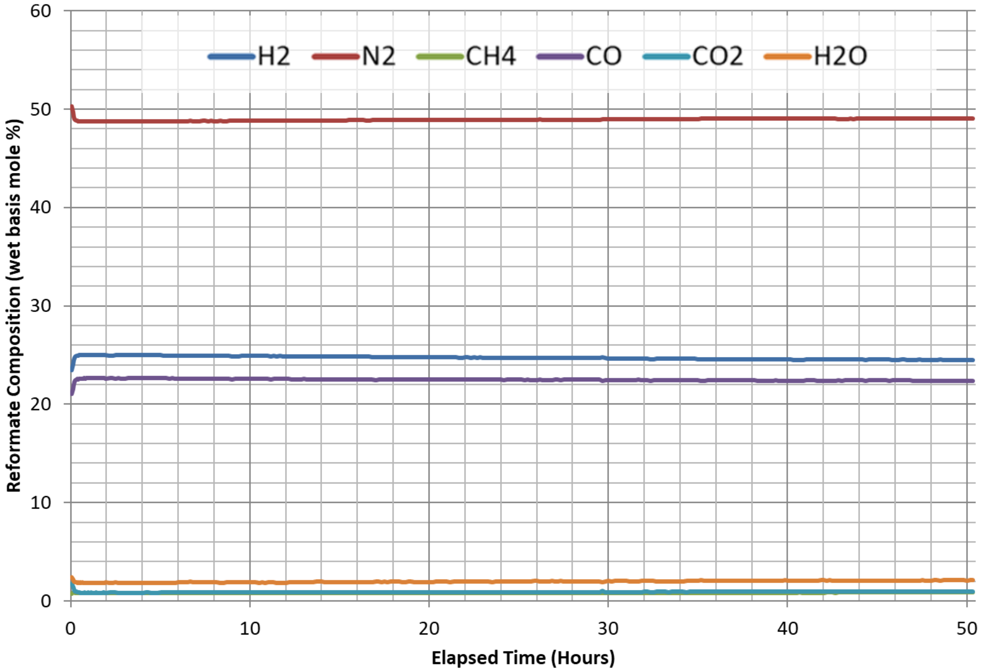
Synfuel C-POX Reformer Development

CPOX Testing @ 5 kW_{th} w. IPK (Inlet Air @ ~200°C; O/C = 1.05, 1 atm)





Stable temperature profile

Data shows >95% of max. theoretical efficiency

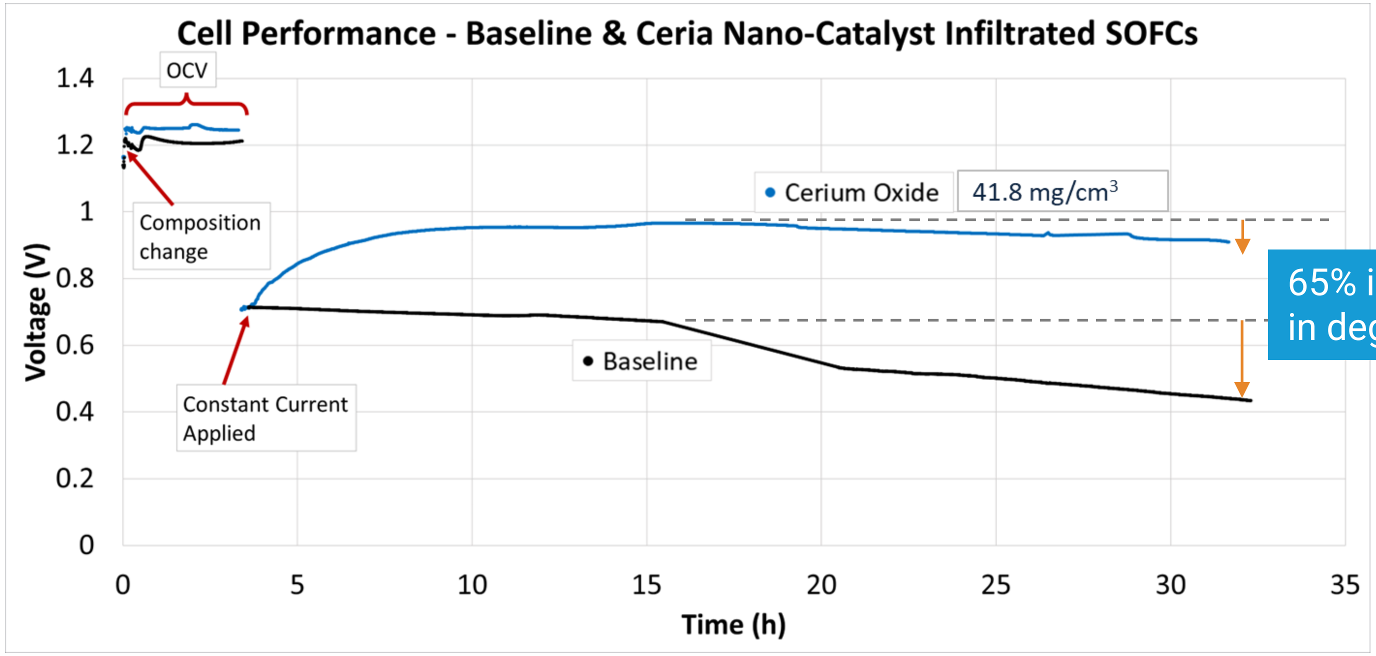
LHV-based efficiency >80%

H_2+CO > 47% (equilibrium H_2+CO is 48%)

Nano Anode Coating Material Development

Nano-Catalyst Evaluation in Accelerated SOFC Tests

CeO_2 deposition with S1 at 1.0 M concentration was replicated in a SOFC to yield a deposition density of 41.8 mg/cm^3.



65% improvement in degradation rate

Test Conditions

- Temperature: 750 °C
- Anode: 20% H_2; **30% CH_4**; 50% N_2
- Cathode: 100% Air

Overall improvement in performance (+170%)
65% improvement in degradation rate [mV/hr]

SOFC Design

Anode Current Collection Layer (CC)
- Added Porosity
70% Fine NiO (0.5-1.5 µm)
30% Fine-grade YSZ (0.35-0.45 µm)

CC: NiO/YSZ

Anode Active Layer (AL)
50% Fine NiO (0.5-1.5 µm)
50% Fine-grade YSZ (0.35-0.45 µm)

AL: NiO/YSZ

Electrolyte
YSZ-8 Electrolyte
25 mm diameter
0.25-0.30 mm Thickness

Electrolyte: YSZ

Barrier Layer (BL)
80% Mid-grade GDC (0.1-0.4 µm)
20% Nano-grade GDC (5-10 nm)

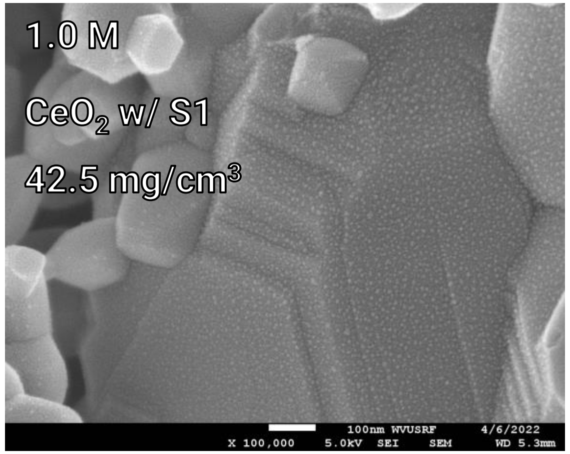
BL: GDC

Cathode Active Layer (AL)
50% LSCF (0.7-1.1 µm)
50% Mid-grade GDC (0.1-0.4 µm)

AL: LSCF/GDC

Cathode Current Collection Layer (CC)
- Added Porosity
70% LSCF (0.7-1.1 µm)
30% Mid-grade GDC (0.1-0.4 µm)

CC: LSCF/GDC



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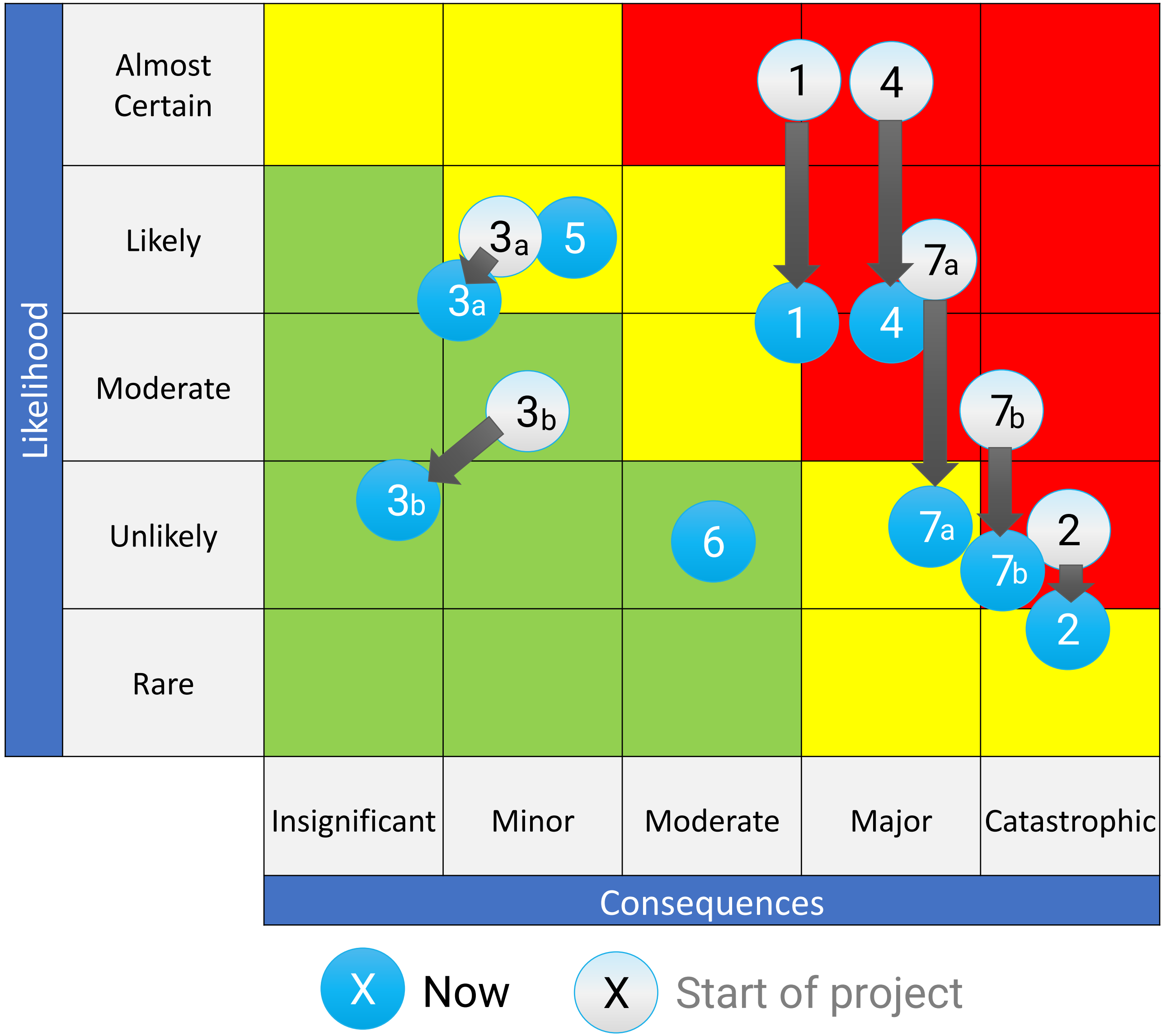
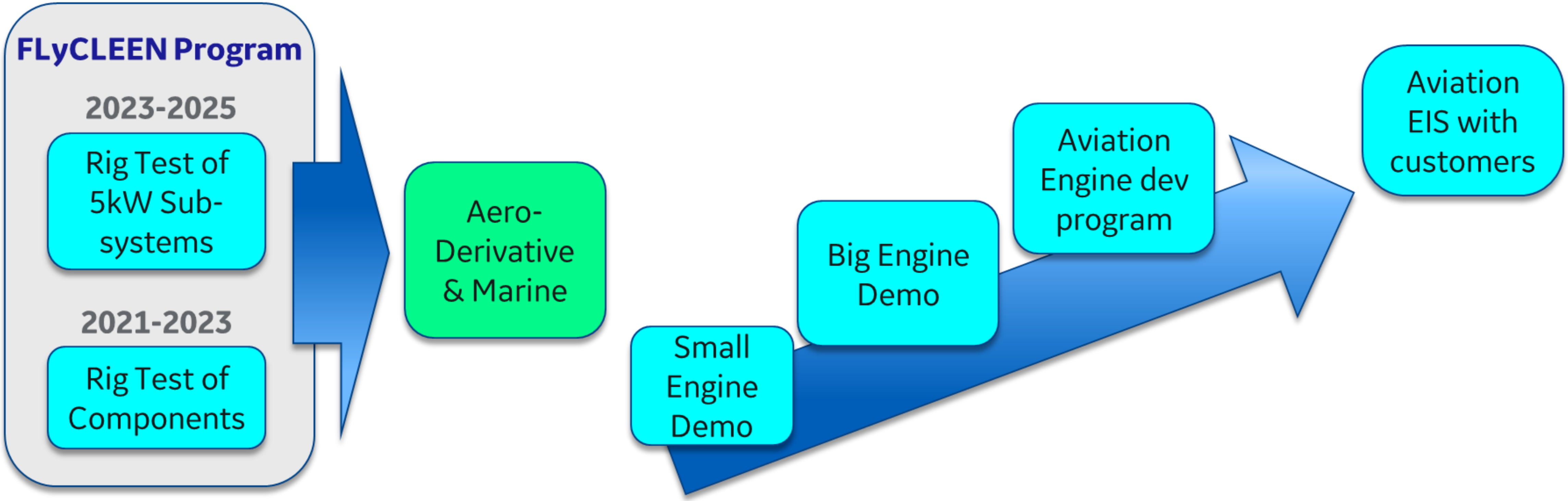
Risk Update

#	Risk
1	SOFC specific power
2	SOFC mechanical integrity
3	Anode degradation a: nano-particle coarsening & long-term stability b: anode porosity
4	Weight of new components
5	Life of new components
6	Projected ESPG cost
7	C-POX reformer a: performance & manufacturability b: durability



Technology-to-Market Approach



GE Research will partner with GE Business Units to commercialize FLyCLEEN technology

Land-based aero-derivative provides early product opportunity

- Offer efficiency benefit & de-carbonization approach for power generation
- Mature reliability for aviation

Q & A

https://arpa-e.energy.gov

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